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the D and F Ionosphere Layers: Why are AM Broadcast Signals Mostly Local

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Abstract

This paper describes a student exercise that uses simple apparatus to enable students to observe signals of opportunity such as local AM broadcast stations, and NIST's time signals, in order to experience how the *D* and *F* ionosphere layers affects low and high frequency (LF and HF) radio propagation and reception. Thus, answer the question of why during the day, only local AM broadcast stations are heard, whereas at night the AM dial is crowded with stations located hundreds of miles away. It also answers the question on why local AM broadcast stations either go off the air at sunset or reduce their power. The required apparatus is relatively low cost, and readily available. By experiencing ionospheric phenomenon, the student will become more knowledgeable about skywave propagation, for HF and LF communication.

Introduction

Inquisitive students will often ask the questions, why are only local AM broadcast signals heard during the day, whereas at night the AM broadcast band is crowded with stations from hundreds of miles away, and why is it during drive time, as the sun is setting, does the radio announcer declare the station will soon be going off the air? While these questions are easily answered by a scientific explanation of ionospheric behavior, it would be better to augment the explanation by having the student experience the behavior themselves by receiving *signals of opportunity* in order to observe skywave propagation and radio signal absorption and thereby become more knowledgeable communication engineers.

We first present the basics of radio propagation and then focus on the theory of sky-wave radio propagation. We then describe the experiments to understand the behavior of the *D* and *F* ionosphere layers with respect to radio signals. By having students observe sky wave radio propagation and the effects of the ionosphere on these signals, they will be better positioned to understand the theory of how this part of the earth's atmosphere enhances or degrades the medium frequency (MF) and high frequency (HF) radio propagation. In the realm of public policy, this paper will provide the student a better understanding of the rationale for the how and why of frequency re-use in the AM broadcast band, and the Federal Communications Commission (FCC) policy of limiting an AM broadcaster's transmitter power and airtime.

Theory

Radio wave propagation - Radio wave propagation can be roughly divided into two categories, *ground-wave* and *sky-wave propagation* [1-3]. Ground-wave propagation is where the wave propagates within the earth's troposphere whose height extends to about 10 km from the earth's surface. There are several means in which a ground wave travels. These include the following: (a) the *direct wave*, whereby the signal travels directly between the transmitter and receiver. While this is line of sight, because air has a index of refraction slightly greater than unity, there is some refractive bending, and thus, the signal may travel slightly beyond the horizon. (b) The *surface wave*, which is also called the *Norton surface wave*. Norton surface waves are waves that travel along the earth's surface in the same way a electromagnetic wave would travel along a transmission line[1]. The losses are dictated by the frequency, the higher the frequency, the greater the signal attenuation. The Norton surface wave permits reasonable propagation of signals below the medium frequency (MF) bands and therefore, depending on the transmitter power, AM broadcast signals can propagate up to a maximum of hundred or miles or so during the day via the surface wave. At frequencies greater than 1 MHz, ***the ground losses are such that the signal will be severely attenuated.*** The amount of loss depends on the earth's conductivity along that path. The surface wave is illustrated in Figure 1. (c) *Tropospheric bending*, where dense air masses in the earth's troposphere will cause refraction of radio waves. Occurance of tropospheric bending is a transient phenomenona, but sometimes enables communication distances of hundreds of mile at frequencies above 50 MHz [2]. (d) *Reflection and diffraction* - the earth's terrain or man-made objects can sometimes enable waves to travel beyond the normal line of sight distances via diffraction or reflection[1,2].

Ionosphere layers – Gas ionization is a process whereby a gas atom or molecule becomes charged by losing or gaining an electron due to external radiation. Ionized gas has some interesting properties with respect to radio waves and depending on the properties will cause the waves to be either absorbed, refracted or reflected. In observing Figures 1 and 2, the ionized gases that form the earth's ionosphere have 3 distinct regions - the *D*, *E*, and *F* layers. The characteristics of each layer are determined by the type of gasses present, gas density and the radiation type (i.e. UV, X-ray, etc.). The *D*-layer has the property that typically absorbs radio signals below 8 MHz, whereas the *E* and *F* layers generally reflect signals below 100 kHz, and refract signals above 100 kHz. Oftentimes this refraction is referred to as "reflection." The frequency values affected and to what degree they are absorbed or refracted greatly depends on solar conditions, time of day, the solar cycle, etc.

Sky-wave propagation – Sky-wave propagation is where the signals between the maximum useable frequency (MUF) and lowest useable frequency (LUF) will either reflect or refract off the *E* or *F* layers of the ionized media in the ionosphere as shown in Figures 1 and 2 below. This will be discussed shortly. In [4], it was observed that NIST's 10 MHz signal could be reliably heard over most of a 24 hour period. Skywave communication distances can be as much as 4000 km, but with multiple hops, the distances can be much greater. Thus, relatively reliable global wireless communication via ionospheric propagation is possible, especially if frequency diversity is employed [4].

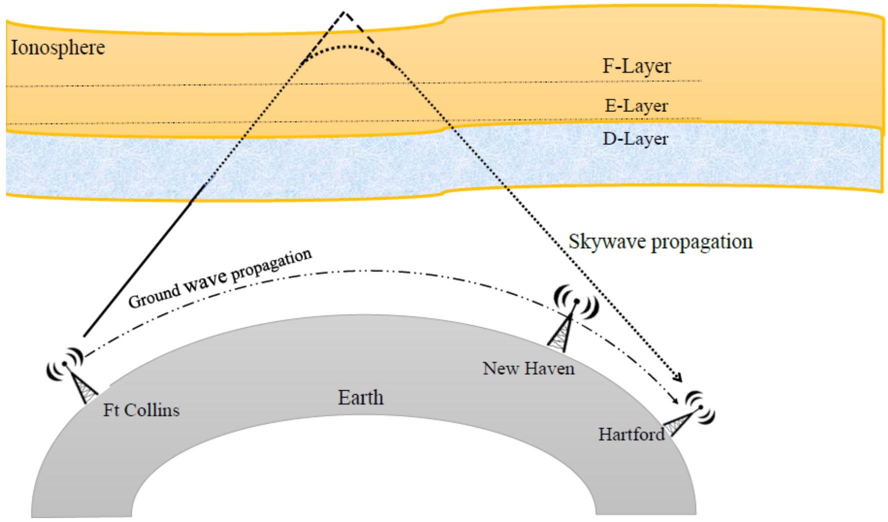

Figure 1. Groundwave and sky wave propagation [4]

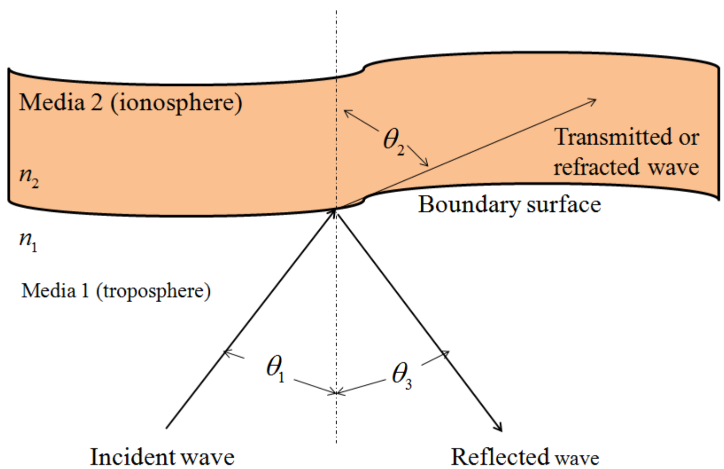

Figure 2. Reflection and refraction through ionized media [4].

Maximum Useable Frequency (MUF) and Lowest Useable Frequency (LUF) – As previously stated, the LUF and MUF are the range of frequencies whereby the signals can propagate beyond the earth's horizon via refraction/reflection off the ionosphere. Both the MUF and LUF depend on solar weather. The MUF is generally at least 15 MHz, but during sunspot maximum period, the MUF may often exceed 50 MHz, and thus long-distance communication is achievable even at the 6-meter band. The MUF is primarily dependent on the degree and type of ionization in the *F* or *E* layers [1,2].

The LUF is caused by signal absorption in the *D*-layer and reduces the frequency in which ionospheric propagation can occur. Signal attenuation is inversely proportional to frequency [2,5] or

$$attentation = k / f^2$$

The *D*-layer is only present during the day when the propagation path is facing the sun and is absent at night. Hence, this explains why during the daylight hours, only local AM broadcast stations are heard, whereas at night time the distant AM stations can be heard.

While the LUF is primarily affected by solar activity and the time of day, its effects can be mitigated by either increasing the transmitter's effective radiated power, changing the type of modulation and/or changing the message bandwidth. For example, during the day, voice transmission with a bandwidth of 3 kHz, may not be effective, whereas on-off keying with a bandwidth of 100 Hz, would enable longer communication distances. Put another way, if a path exists in the *F*-layer, but the signal is being attenuated because of absorption of the D-layer, a higher transmitter power may overcome these losses.

The LUF is typically 8 MHz or below, but during times of unusual solar activity it can be significantly higher and may even exceed the MUF. See reference [2] for more information on the LUF and MUF with respect to practical HF ionospheric communication. In any case, because most communication below 500 kHz is done by the surface wave, the LUF is mainly relevant above 500 kHz. See references [6,7] for additional information on radio propagation.

Experimental

Our experimental apparatus is the same as used in a previous project [4] and consists of a Kenwood model TS-590 short-wave receiver, and an end-fed, 100-foot wire antenna strung around the woods of Old Lyme, Connecticut. The antenna was L-shaped, and oriented in both the north-south and east-west directions. Data collection was done in October, December and January.

Initial benchmark using 2.5 MHz NIST broadcasts: As a benchmark, and to observe the time interval when *D*-layer absorption occurs, we first measured the signal-strength of NIST's WWV time/frequency beacons at 2.5 MHZ over a 24-hour period for both October and December times. For October, sunrise and sunset were 6 A.M. and 5 P.M. respectively and for December, sunrise and sunset were 7:15 A.M. 4:30 P.M respectively. The signals strengths versus times are plotted in Figure 3 and varied from 0 to 3 with a 0 meaning the signal is not heard, and a 3 a strong signal. First, observe that the 2.5 MHz signal has a maximum signal strength from the interval of sunset to sunrise, when the propagation path from Fort Collins, CO to Old Lyme, CT is not illuminated by the sun. Secondly, observe that the 2.5 MHz signal is heard for a longer period in December when the days are relatively short versus October, when the days are longer. Thirdly, note that the reception and relatively strength of the 2.5 MHz beacon is coincident with the sunrise and sunset events and finally note that the 2.5 MHz beacon is never heard at noon, and has maximum strength at midnight. It would thus be expected during the day only local stations would be heard, whereas at night, stations hundreds of miles away would be heard.

Note that while the 2.5 MHz beacon from Fort Collins to Old Lyme, is not received during daylight hours because the distance, power levels and frequency are such that ground wave communication is not possible. However, this is not the case with the closer 3.3 MHz CHU-Canada time signal. Crilly [4] reports that the 3.3 MHz CHU-Canada time signal can be received at Old Lyme 24/7 via ground-wave propagation. Note that the CHU transmitter power and distance to Old Lyme is 3 kW and 300 miles respectively. In comparison, the NIST transmitter distance to Old Lyme is approximately1800 miles and thus the only viable path for the 2.5 MHz signal would be sky-wave. Therefore, if the AM broadcaster has enough power, it may be received either via ground wave if the distance is less than a few hundred miles or the increased power may mitigate the effects of *D*-layer absorption. Having said this however, our experiments so far have not shown sky-wave propagation effects during daylight hours at frequencies below 5 MHz.

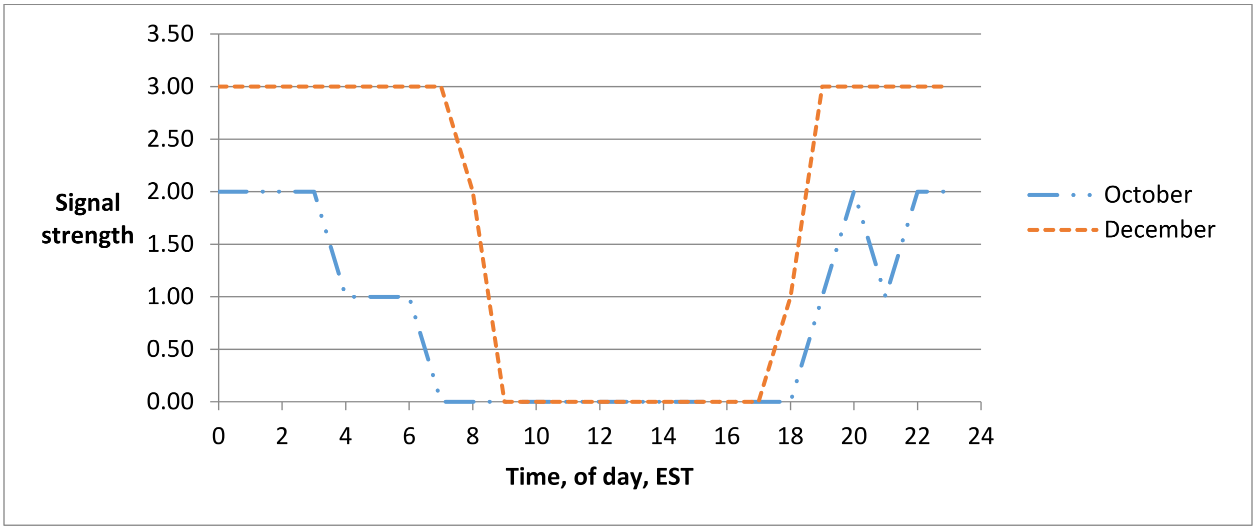

Figure 3. Signal strength versus time of day for the WWV signals at 2.5, MHz for October and December. Note that 0 = 24 = midnight. Measurements taken at Old Lyme, CT. Note that sunrise/sunset for October is 6 AM/ 5 PM EST and sunrise/sunset for December is 7:15 AM/4:30 PM.

Daytime AM broadcast radio testing: During the late morning, early afternoon time interval, we scanned the AM broadcast band from 540 kHz to 1700 kHz and recorded the frequency, call sign and station location of those stations that were audible (i.e. not buried in noise). The station locations were then plotted on the map of Figure 4. As expected, most of the 38 signals received were within the northeast USA or within a 100 mile radius of Old Lyme. However, two broadcast stations were received at distances of about 300 miles or so, one in Baltimore, MD, and the other in Buffalo, NY. Both had a transmitter power of 50 kW, a level much greater than most other stations received. The increased power enabled the signal to overcome signal attenuation due to ground wave losses. Also received and plotted during this time was Canada's 3.3 MHz CHU time signal. Note from Figures 3 and 4 that no signals at or below 5 MHz were received during daylight hours if the distances were much greater than 300 miles.

Nighttime AM broadcast radio testing: During late evening interval, when most of the USA was no longer facing the sun, and the *D*-layer was no longer present, reception conditions drastically changed. In some cases, the day time stations went off the air and were replaced by different

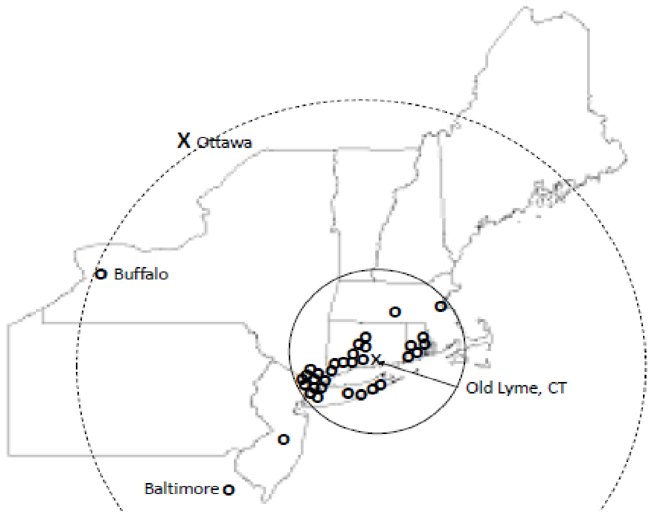

Figure 4. Map showing location of AM broadcast radio stations heard during late morning at Old Lyme, CT. The circles represent radii of 100 and 300 miles respectively. Station marked with an X indicates the location of Canada's 3.3 MHz CHU time signal.

stations, much further away. The AM band was rescanned and only those stations that were not heard during the day or those that were outside a 300 mile radius were recorded. These are reported in Figure 5. By necessity, as done during the daytime, we only recorded the stronger ones. Like the daytime period, some stations were buried in the noise or interference. Because there was both ground and sky wave paths, many stations received suffered from multipath and other forms of interference. This meant only the strongest stations were clearly received. The furthest signals heard was the NISTs 2.5 MHz beacon. The other stations, such as the two from Chicago, were heard at distances up to 800 miles.

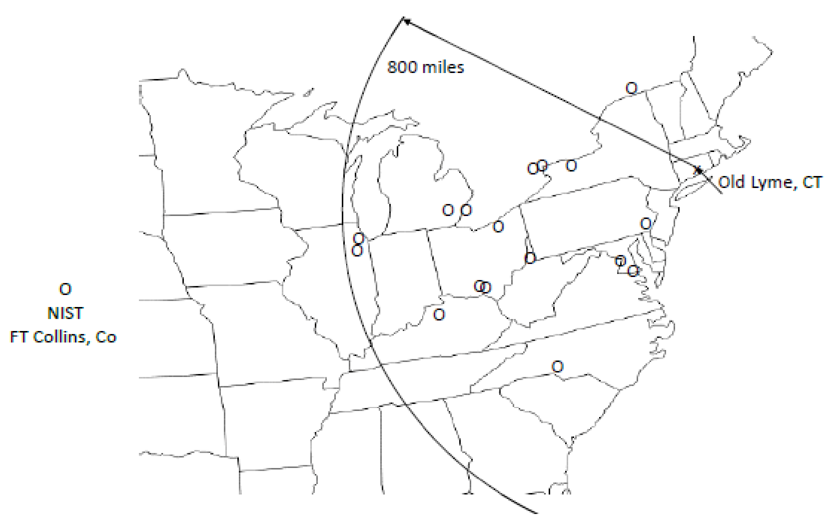

Figure 5. Map showing location of AM broadcast radio stations heard around the late night hours. Note, the 2.5 MHz NIST beacon was only heard during the night interval. The NIST transmitter was 1800 miles from Old Lyme.

FCC licensing policies and frequency re-use: During afternoon drive time, especially around mid-December, while listening to a particular AM station, one will often hear the announcer state the station will be going off the air. The inquisitive person will ask themselves, why is this so?

First, with the AM, FM and TV broadcast bands, there are only a finite number of frequency slots that can be assigned to commercial stations. In the USA, there are many more stations than available frequencies, hence the need for frequency re-use. With FM and TV frequencies, that operate on the VHF and UHF bands, coverage is line of sight regardless of the time of day, thus facilitating frequency re-use by a different station outside the 30 to 100 mile radius of a given station local or metropolitan region. Of course, line of sight distances, particularly on the VHF and UHF bands are greatly a function of antenna height. On the other hand, with AM broadcasts, during the day, coverage is local, that is propagation is either via the Norton wave or line of sight and thus the broadcast will generally not extend more than 100 to 300 miles. As long as the sun is out, and the distance between stations is on the order of a few hundred miles, frequency re-use by another station will not cause interference.

However, when the sun sets in a given locality, to minimize interference, the FCC as a condition of a station's license, may either require that station to go off their air, or reduce its effective power during night-time hours. Hence, seemingly during drive hours in the winter months, your local station may suddenly and unexpectedly go off the air.

Conclusions

By using a basic AM or shortwave receiver, students can become familiar with ground-wave and sky-wave propagation. Using the AM broadcasters, CHU-Canada and NIST WWV as signals of opportunity, students can readily observe *D*-layer absorption, ground-wave propagation, and *E* and *F* layer propagation. Thus, during the day, they observe the primary path is ground-wave and thus communication is local, whereas at night, the ionosphere acts to enable signals to reach destinations hundreds and in some cases several hundreds of miles away. Thus, students will experience and thereby better understand that HF and MF communication via sky-wave is an alternative to satellite relay, or tower relay for long distance communication.

There were a few other lessons learned from this exercise. These include the following (a) Because it's possible for a radio wave to travel both via sky and ground wave, the student will observe multipath interference, (b) how interfering AM signals cause background whistles, (c) frequency diversity enables more reliable communication, and (d) how the product detector has better weak-signal performance than an envelope detector.

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